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A semantic approach to enrich user experience in museums through indoor positioning

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Abstract. This article presents a novel ontology aiming to connect an Indoor Positioning System (IPS) to Europeana, the European Union digital platform for cultural heritage. The main purpose of this system is to deliver information about Cultural Heritage Objects (CHO) to users navigating in museums, when they approach certain pieces of art. Although different semantic works have been previously published regarding the problem of finding optimal paths with IPS, the novelty of this work is the combination of indoor positioning and a semantic view of cultural objects. This ontology enriches the experience of users and offers a new way of enjoying art. The paper shows the effectiveness of the proposed ontology to connect a widely known database to a wireless positioning system. The potential of the developed method is shown using data obtained from the Royal Museums of Fine Arts of Belgium, one of the most important European art galleries, with more than six thousand master pieces listed in Europeana. Some experiments have been also carried out in the Old masters Museum, one of the constituent museums of the Royal Museums that is dedicated to European painters from the 15^{th} to the 18^{th} centuries.

Keywords: indoor positioning, WPS, RGB-D sensors, WiFi positioning, *fingerprint*, *depth map*, OWL, ontology, SPARQL, ubiquitous computing, user experience, Europeana, Royal Museums of Fine Arts of Belgium

1 Introduction

Modern Indoor Positioning Systems (IPS) facilitates the interaction of users with the environment, estimating the position of people or objects inside a building [9]. This kind of systems can be useful in certain environments, where the location of users is considered as a trigger for different operations (e.g., enable or disable machines, open doors, information management . . .).

This interaction between people and the environment involves a set of concepts, entities and the relationships among them, which are defined in the ontology. In this article, a novel ontology is presented aiming to connect a previously developed IPS [12] to Europeana.

Europeana [17] is the European Union's digital platform for cultural heritage, giving access to different types of content from different institutions. More than 3,000 institutions across Europe have contributed to Europeana. The collections let users explore Europe's cultural and scientific heritage from prehistory to the modern day. The digital objects in Europeana are stored in the cultural institution and are hosted on their networks. Europeana collects contextual information or metadata about items. The data.europeana.eu Linked Open Data pilot dataset contains open metadata on approximately 2.4 million texts, images, videos and sounds.

The rest of the paper is structured as follows: Section 2 explores previous works related to the techniques used in this article. In Section 3, the developed ontology is described, illustrating how it is linked to the positioning systems and how the navigation system works. Finally, Section 4 shows carried out experiments and Section 5 remarks the main features of the presented system and proposes future works.

2 Overview of related work

2.1 WPS and RGB-D Positioning

WiFi Positioning Systems (WPS) are mainly founded on the *fingerprinting* technique [19]. This technique creates a map of the environment recording, in each point, the received signal from a mobile phone (i.e. *Received Signal Strength Indication* (RSSI)) . This map is used afterwards to obtain the position of a user in real-time, comparing the values received from the user's portable device to those stored in the map.

One of the main advantages of WPS solutions with respect to similar technologies (e.g., RFID or Bluetooth) is the use of devices commonly installed in inhabited environments (i.e. routers), whereas other solutions require dedicated infrastructure. Also, WPS can be used to provide Internet access aiming to share information.

With respect to people and objects positioning, some technologies based on computer vision (e.g., RGB-D sensors) have been increasingly used to deliver more precise results, such as the method *Kinect Positioning System* (KPS), analyzed in [22]. A more complex solution is shown in [24], where the authors present an indoor human tracking application using 2 depth-cameras. More recently, in [26], authors proposed a model for merging Kinect trajectories. Using the global coordinates at the same time stamp, their system is able to determine the distance between two skeletons in order to discern between different users.

The developed IPS presented by our team in [12] combines two widely-known technologies: (WPS), extensively used in indoor positioning, and computer vision by means of RGB-D sensors. The trajectory of users is considered in both ways: exploiting the WPS trajectory and the trajectory of the skeletons of the users in the *depth map*. The skeletons are obtained by means of the techniques presented in [27] [6], where authors propose new algorithms to quickly and accurately predict 3D positions of body joints from depth images. The mentioned IPS is the base of the work presented in [13], where the system tracks the position of visitors in a museum.

2.2 Knowledge engineering

In the field of computer science, an ontology [15] [14] is the definition and classification of concepts and entities, and the relationships between them. Ontologies use entities in the universe of discourse (e.g., classes, relations, functions, or other objects) and formal axioms that constrain the interpretation and well-formed use of these terms. They can be represented in the W3C Web Ontology Language (OWL) [8], which is a Semantic Web language designed to represent knowledge about things, groups of things, and relations between them.

In the last decade, different approaches have been presented to deliver semantic views of the indoor navigation problem. In [28], authors propose an Indoor Navigation Ontology (INO), which supports the path searching and the presentation of tasks of a navigation system. More recently, an extended version of INO is used in [20], in which an augmented reality solution is also considered to provide a richer experience. Another approach for indoor routing was developed by [11], where authors propose a different ontology (ONALIN) that provides path searching for individuals with special needs and preferences. In [18], authors present a location-based service (LBS) to figure out the path between a starting point and a destination. This is based on an ontology that enriches the standard positioning since users can share, manage and query data semantically. OGC GeoSPARQL [7] offers support for representing and querying geospatial data on the Semantic Web. However, it is mostly prepared to represent geometry topology, like polygons, instead of being used as a tool for positioning purposes.

2.3 About data in Europeana

Europeana is a project developed by the European Commission to incentive member states to digitalize and enhance digital preservation in Europe. The portal provides free access to a wide array of digital content. It allows in a simple but powerful way to find resources from all over Europe. It contains over 50 million records. These featured datasets represent over a million of the best, openly licensed, directly accessible media objects - books, photos, art, artefacts, audio clips and more. Europeana has several ways to retrieve data. Information can be obtained by REST API Standard over HTTP, which returns JSON data, or by Annotations REST API, which returns JSON-LD. Other possibilities include OAI-PMH Harvest data via the OAI-PMH protocol and Linked Open Data Queries retrieving data in SPARQL. Data can also be linked to external data sources, such as the Swedish cultural heritage aggregator, GeoNames, the GEMET thesaurus or DBPedia.

The use of an ontology in this system, in order to connect it to Europeana, facilitates a dynamic behavior, adding new functionalities in a simpler manner without modifying data models.

3 Analysis of the system

As mentioned in previous sections, the main purpose of this work is the development of an ontology that links an indoor positioning system to the Europeana database, aiming to deliver information about Cultural Heritage Objects (CHO) to museums' users, considering their location inside a building. This information about master pieces is retrieved from the database through SPARQL queries.

Even if this system could be applied in every museum in Europe whose works are stored in Europeana database, Royal Museums of Fine Arts of Belgium (Brussels, Belgium) has been chosen to illustrate this paper. Consider, for instance, the search for information about the famous painting of Rogier Van der Weyden "Déploration". After the corresponding SPARQL query, the information shown in Table 1 is provided.

Longitude and latitude coordinates of the Royal Museums can be easily retrieved. However, the position of the pieces inside the museum is not in Europeana. Therefore, it is needed to create another relation giving the precise room and position of a masterpiece to be used with the developed system. In order to do that, an ontology has been created.

Table 1: Result for the query of "Déploration"

CHO identifier	http://data.europeana.eu/proxy/provider/2048001/Athena_Plus_ProvidedCHO_KIK_IRPA_Brussels_Belgium_AP_10325768
title	"Déploration"@fr
creator	"Van der Weyden, Rogier"@fr
date	"1441/1464"
type	"tableau[peinture]"
subject	"event"
format	"peint"
provenance	"Object: Musées Royaux des Beaux-Arts de Belgique, Bruxelles"
provider	"AthenaPlus"
dataprovider	"KIK-IRPA, Brussels (Belgium)"
mediaURL	http://balat.kikirpa.be/image/thumbnail/B117883.jpg

3.1 New ontology for obtaining the position of a CHO

As previously mentioned, an ontology is composed of different elements. Classes provide an abstraction mechanism for grouping resources with similar characteristics. In this particular case, two OWL class identifiers have been predefined, namely the classes *Thing* and *Nothing*. The extension of *Thing* is the set of all individuals, whereas for *Nothing* it is the empty set. Consequently, every OWL class is a subclass of *Thing* [8]. The individuals in the class extension are called the instances of the class. If a class is defined as a subclass, the set of individuals that accepts should be a subset of those individuals in the parent class.

OWL distinguishes two main categories of properties to be defined in an ontology: Object properties, which link individuals to individuals; and Datatype properties, which link individuals to data values.

Domain and range are axioms used in the inference process. Both are defined as built-in properties. A domain axiom (marked as green arrows in Figure 1) links a property to a class description and asserts that the subjects of such property statements must belong to the class extension of the indicated class description. A range axiom (black arrows in Figure 1) links a property to either a class description or a data range. This axiom asserts that the values of this property must belong to the class extension of the class description or to data values in the specified data range.

The ontology of Figure 1 has been implemented. As shown, it delivers different types of information.

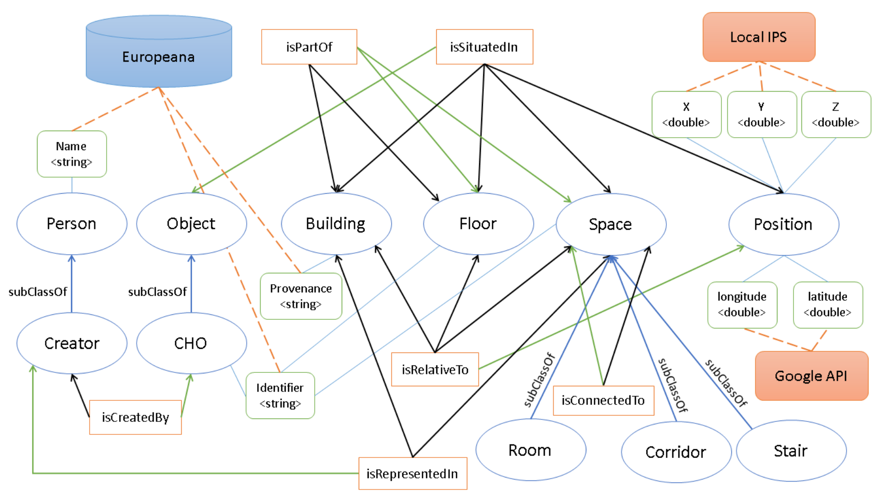


Fig. 1: Implemented ontology where domain and range axioms are marked as green and black arrows respectively.

There are six general subclasses of *Thing*: *Person*, *Object*, *Building*, *Floor*, *Space* and *Position*. Also, *Creator* is a subclass of *Person*, *CHO* is a subclass of *Object*, and *Room*, *Corridor* and *Stair* are subclasses of *Space*.

Person refers to all kinds of individuals, but *Creator* just refers to the creators mainly retrieved from Europeana. The data property "Name" of type $< string >$ accepts values as "Van der Weyden, Rogier". The class *Person* allows extending the system with other types of individuals: producers, owners, people represented in the CHO, etc.

Object refers to all kinds of objects that can be located inside a building: a computer or a table in a room, a screen or TV, a painting on a wall, etc.

The extension of the class *CHO* is composed of particular objects with an identifier to link with Europeana. The data property "Identifier" of type $< string >$, which is an identifier in Europeana, accepts values as shown in Table 1.

Building is the place related to the host institution. It has the data property "Provenance" of type $< string >$ that accepts values as "Musées Royaux des Beaux-Arts de Belgique, Bruxelles".

Regarding spatial-related classes, the class *Floor* represents a floor of the building where there are several spaces (class *Space*). These spaces are represented by the subclasses *Room*, *Corridor*, and *Stair*. *Floor* and *Space* have also identifiers in order to know their particular names. For example, the room with identifier "70_Weyden" (as shown later in Figure 3), is the one where the painting "Déploration" is exhibited. This room is part of the floor labelled as "Second floor".

Position is the class indicating the position (local or global) of an object. It contains three data properties "X", "Y", "Z", of type $< double >$ that include a relative local position with respect to a space, a floor or a building. The other two data properties, "longitude" and "latitude", of type $< double >$, are not relative to a space, floor or building. These values are used for global positioning with Google APIs as will be explained later. Note that the system is flexible in terms of establishing relationships between spaces, floors or buildings and this can be modified according to particular cases.

Furthermore, it is worth mentioning several object properties, which link individuals to other individuals. The object property "isRelativeTo" indicates that an instance of the class *Position* is relative to an instance of the class *Building*, *Floor* or *Space*. It is subsequently relative to the subclasses *Room*, *Corridor*, and *Stair*. This property is used for local positioning, where the three data properties "X", "Y", "Z" are relative to a particular building, floor or space.

The object property "isPartOf" indicates the place where spaces or floors are located. For example, a room is part of a floor and also part of a building. Simultaneously, a floor is part of a building.

The property "isSituatedIn" makes reference to the place where an object is situated. For example, the painting "The Census at Bethlehem", of Pieter Bruegel the Elder, is an instance of the class *CHO* situated in the room with identifier "68_Bruegel" and also situated in the floor with identifier "Second floor". Subsequently, it is situated in the building with the provenance "Royal Museums of Fine Arts of Belgium".

The property "isConnectedTo" is used to obtain the optimal path between two spaces, as shown in the next sections. The rooms are connected to other rooms, corridors or stairs. As will be shown in Section 3.5, A* algorithm [16] has been used to find the shortest path between two rooms.

Finally there are two object properties related to authors. The property "isCreatedBy" means that a CHO has been conceived by a creator. The CHO previously mentioned, which refers to "Déploration", was painted by the creator with the name "Van der Weyden". And the property "isRepresentedIn" indicates where author's artworks are displayed.

3.2 Linking an IPS with the ontology

The presented ontology can be linked with two different classes of IPS: one of them based on global positioning and another one oriented to local positioning. The difference between them is whether the coordinates they return are global to the Earth or relative to a certain building, floor or space (usually rooms).

The local positioning systems are more precise in indoor environments. For this reason, it is better to use a global positioning system, like Google API, to identify whether the user is in a building, i.e. Royal Museums of Fine Arts of Belgium, Prado Museum or Louvre Museum. Then, the local IPS, as [12], is used for indoor positioning delivering precise coordinates.

Considering this combination of IPS, the proposed system figures out which is the nearest artwork with respect to the user, by filtering pieces situated at less than 5 meters and ordering them by distance. This distance is implemented by means of the Euclidean distance between the user position and the position of the artwork. The system implements an SPARQL query, which makes use of federated queries [23] to access to the remote SPARQL endpoint of Europeana.

The two mentioned types of IPS are explained in Sections 3.3 and 3.4.

3.3 Estimating position by means of Google and Android APIs

Android provides an API in android.location [1] delivering the position of a user according three different methods: GPS, Cell-ID, and Wi-Fi. The system returns the position to a Location Listener object that invokes a method each time a new Location object is received. The determination of the best location, if there are several results from the different methods, is decided by means of parameters related to accuracy, speed, and battery-efficiency.

Google also provides a Location Services API [5]. According to the location Android API [2], Google Location Services API provides a more powerful and high-level framework, which automatically handles location providers, user's movement, and location accuracy. It also provides a method to establish fences surrounding a location and detection when the user is inside the area.

Finally, Google Maps Geolocation API [4] provides a web service by means of HTTPS and using POST. This service receives a list of cell towers and a list of WiFi routers, obtained by the client, with their respective signal strength. The service returns the location with longitude and latitude and the accuracy. The communications with the service are established using the JSON format.

The created ontology is flexible and able to assign a value of longitude and latitude to a position instance. Note that all the previously described systems return the user's location using longitude and latitude values. In order to combine Google APIs with the presented ontology, it is initially better to obtain the closer building to the user by means of Vincenty's formulae [29], used in geodesy to calculate the distance between two points on the surface of a spheroid. Later, it is possible to obtain the closest CHO by means of Haversine formula [21], method to calculate the distance between two locations in a simple way. It has an error because the radius of the sphere is not the same in all parts of the Earth. When two locations are close, it is possible to use a medium radio of 6371 km with minor error.

Some libraries like [10] or embedded Javascript [30] allow extending SPARQL functionalities. The ldodds:Distance function calculates the distance between two geographic coordinates based on longitude and latitude.

3.4 Estimating position by means of depth maps and WiFi networks

A generalized version of the previous work [12] has been used for indoor positioning purposes. The proposed system is used for obtaining the identification and the user's position in a scenario composed of different rooms where there are several people carrying smartphones. Two or more RGB-D sensors are situated in each room for obtaining the coordinates of users by means of their skeletons. The skeletons are obtained with the technique presented in [27] [6], where authors propose new algorithms to quickly and accurately predict 3D positions of bodies from depth images.

Users, or visitors in the case of museums, carry smartphones that establish a connection to some accessible network. These smartphones obtain RSSI data and synchronously send them to a central web server. Simultaneously, this central web server obtains body information from different RGB-D sensors.

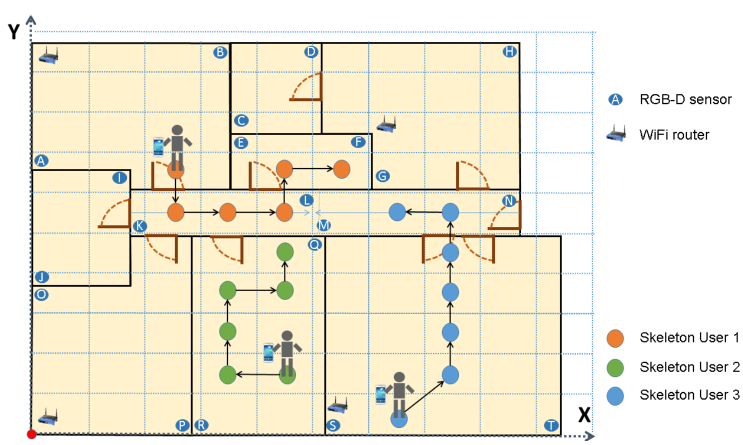


Fig. 2: Skeleton trajectories in a running example of the IPS developed. Twenty RGB-D sensors are deployed in the scenario.

Figure 2 illustrates this system. Several users can be seen with their corresponding paths at certain time stamps. This system requires at least two RGB-D sensors in each room and all users need the application running. Eight WiFi access points (i.e., routers) have to be accessible in the entire scenario to obtain good WPS positioning.

The used SPARQL query obtains the nearest artwork with respect to the user. It filters pieces situated in a range of 5 meters. The query makes use of federated queries [23] to access to the remote SPARQL endpoint of Europeana and makes use of AQR functions [25] to calculate Euclidean distances. Note that a SPARQL Jena server [3] has been created to support the ontology.

3.5 Obtaining optimal path between two rooms

The presented ontology has been also prepared for obtaining the best path between two rooms. As can be seen in Figure 1, rooms are connected to other rooms, corridors or stairs. A* algorithm [16] has been used to find the shortest path between two rooms, which are considered as nodes in a graph. Users can select a CHO in the catalogue and the system calculates the optimal path from their current position.

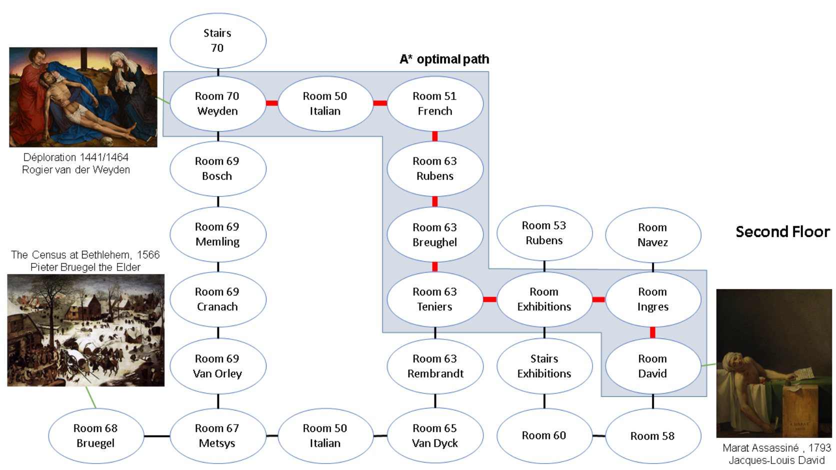


Fig. 3: Obtaining optimal path between two rooms

In Figure 3, an A* algorithm returns the optimal path to go from the room "David", where Jacques-Louis David's painting "Marat Assassiné" is located, to the room "70_Weyden", where users can find Weyden's painting "Déploration".

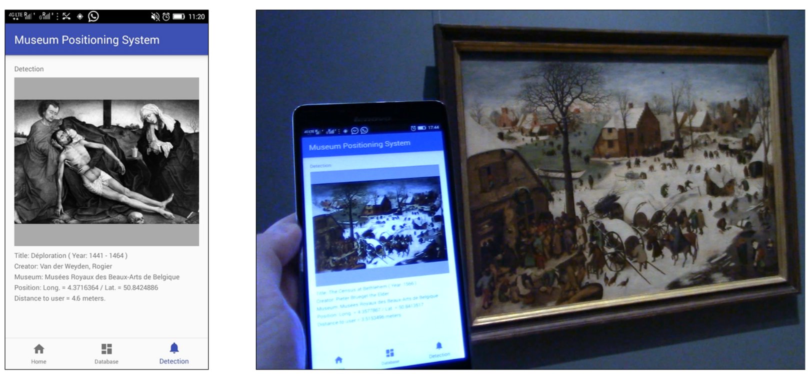
The rooms are subclasses of *Space*, and in Figure 3, the link between them is the object property "isConnectedTo", shown in the previous ontology.

4 Experiments

Aiming to test the proposed ontology, an experiment has been designed and carried out in the Royal Museum of Fine Arts of Belgium. This experiment consisted of two stages, as detailed in the following.

First, a user walked around the museum, registering the location of each painting linked to Europeana by means of an Android application which has been developed for this purpose (see Figure 4a) and installed in smartphones. The position of each masterpiece is delivered by the Google API and stored in the database. Note that this process is only performed once, and it does not need to be repeated at least paintings are relocated inside the museum. Four paintings were chosen and their positions registered in the database.

Later, a different user navigated through the rooms, retrieving information from Europeana with the mentioned application installed in his cellphone. The 4 studied paintings were visited 5 times each, delivering the application the correct information every time the user was in a range of 5 meters. Figure 4b shows an example where the system is detecting the masterpiece "The Census at Bethlehem" by Pieter Bruegel.



(a) Android application (b) Detecting painting

Fig. 4: Experiments developed using Google Location Services API.

5 Results and Conclusions

This article presents a new ontology for connecting a previously developed Indoor Positioning System (IPS) and Europeana, the EU digital platform for cultural heritage. As shown, the proposed ontology can be used in a museum for enhancing the user experience, by infering knowledge about cultural heritage objects.

The article also explains an option to obtain the optimal path between the position of the user and a painting in the museum based on the A* algorithm.

In order to test the developed ontology, some experiment has been carried out, taking advantage of the Google Location API. Even though data from the ontology was correctly retrieved and the position of users was properly obtained by means of data from cell towers and WiFi networks, the installation of more WiFi access points could improve the positioning.

Future works include the testing of the mentioned IPS system (combining RGB-D sensors and WPS), together with the solution presented in this paper, in a museum environment.

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